URI Contribution Towards Improving the GFDL/GFDN and HWRF Operational Models Under JHT Funding and Future Plans

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NOAA Testbed USWRP Workshop

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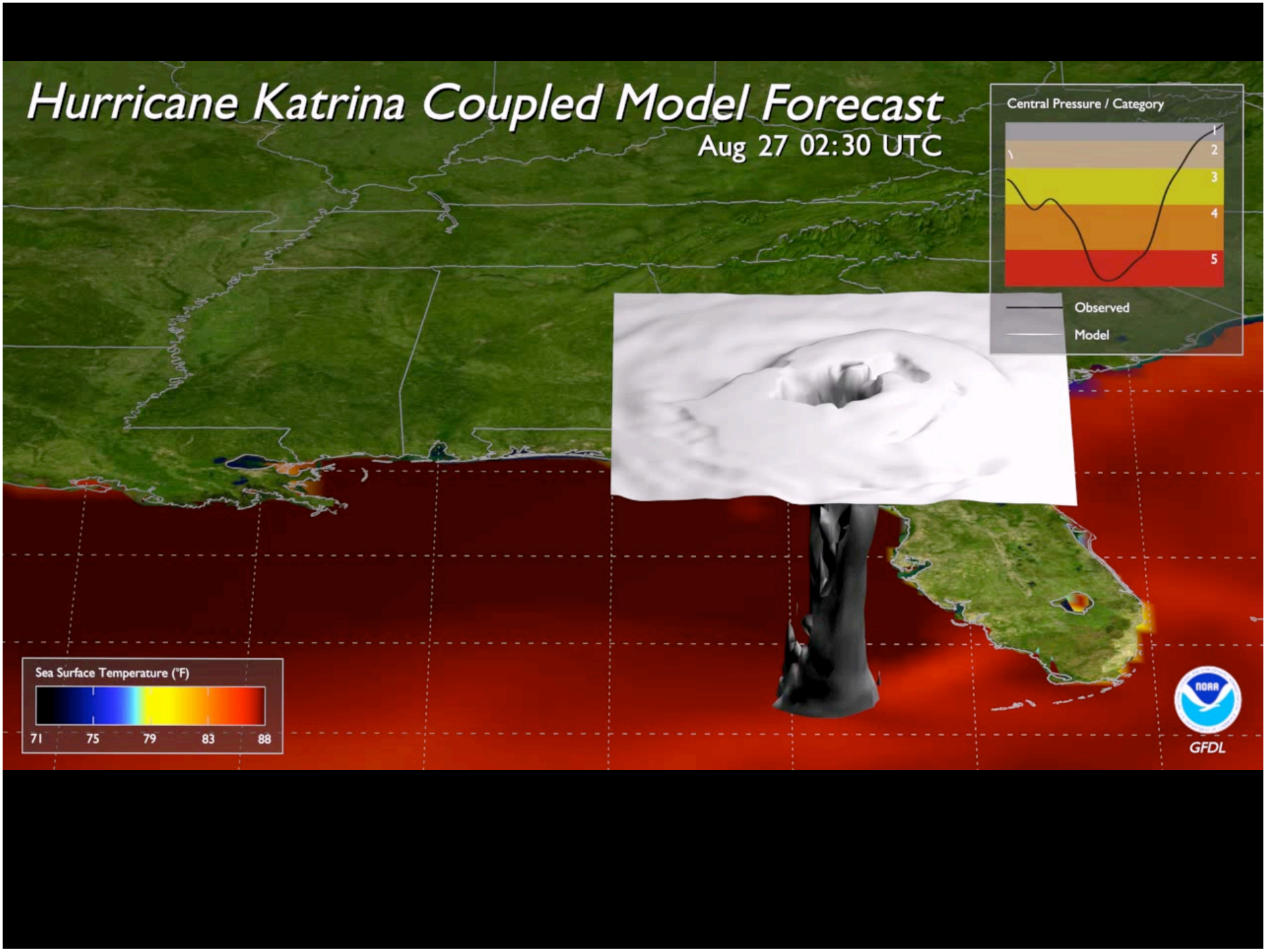
Coupled Hurricane-Ocean Models Transitioned to Operations

- 2001 – GFDL/POM at NCEP in Atlantic basin (3-D coupling)
- 2004 – GFDL/POM at NCEP in Eastern and Central Pacific basins (1-D coupling)
- 2007 – HWRF/POM at NCEP in Atlantic basin (3-D coupling)
- 2008 – GFDN/POM at FNMOC in Atlantic basin (3-D coupling) and all other ocean basins (1-D coupling)
- 2009 – GFDN/POM at FNMOC in N. Pacific basin (3-D coupling)

Model Improvements Transitioned to Operations

- 2003 – New GFDL/POM ocean configuration and data assimilation package with improved Gulf Stream initialization
- 2005 – Increased resolution of GFDL model
- 2006 – New GFDL/POM ocean data assimilation package with improved Loop Current and WCR initialization in the Gulf of Mexico & improved air-sea momentum flux parameterization
- 2008 – Further improved GFDL/POM and HWRF/POM ocean data assimilation package with ability to define multiple WCRs and CCRs in the Gulf of Mexico

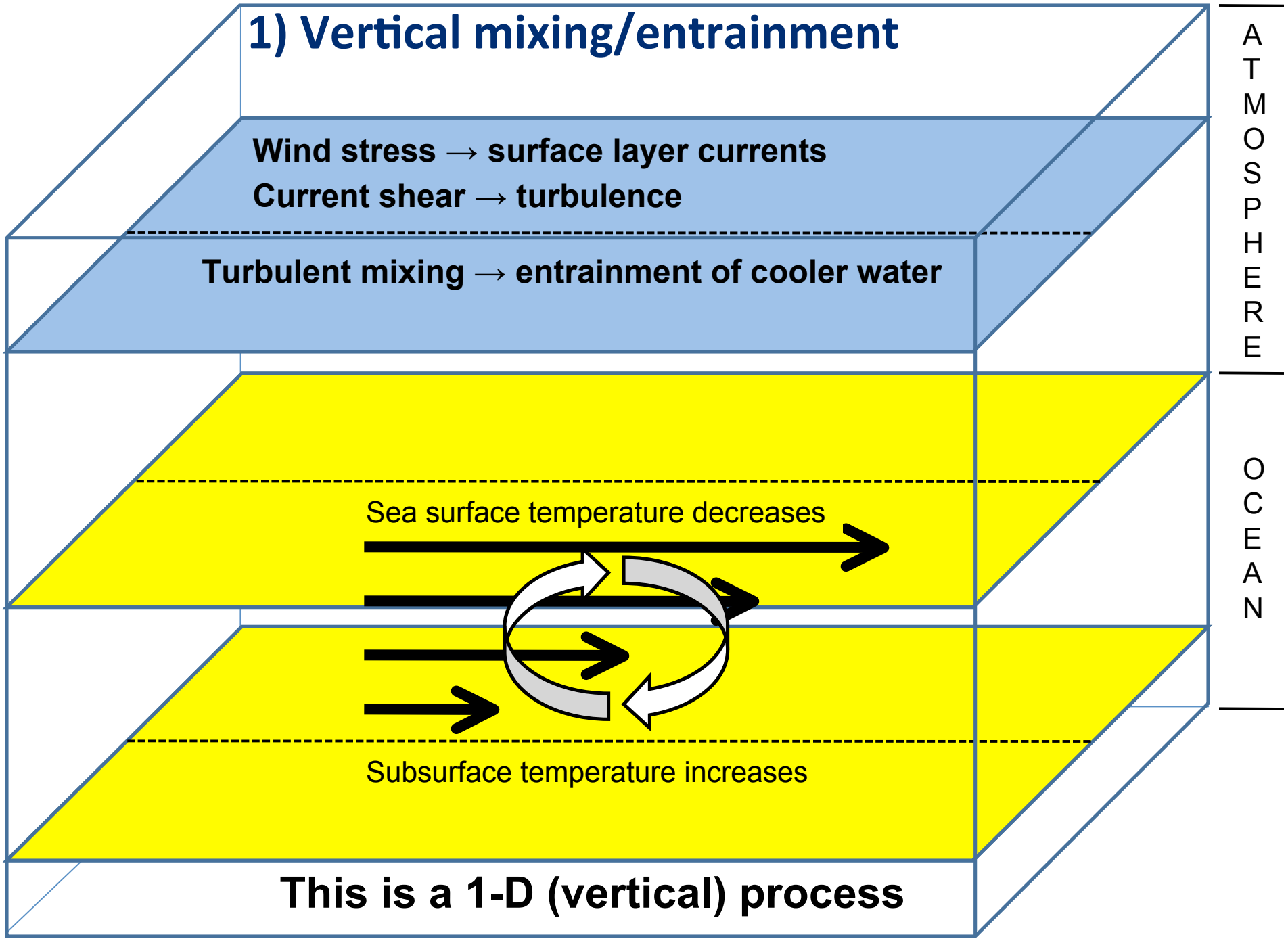

Hurricane Katrina Coupled Model Forecast
Aug 27 02:30 UTC
Central Pressure / Category
1
2
3
4
5
Observed
Model
Sea Surface Temperature (°F)
71
75
79
83
88
NOAA
GFDL

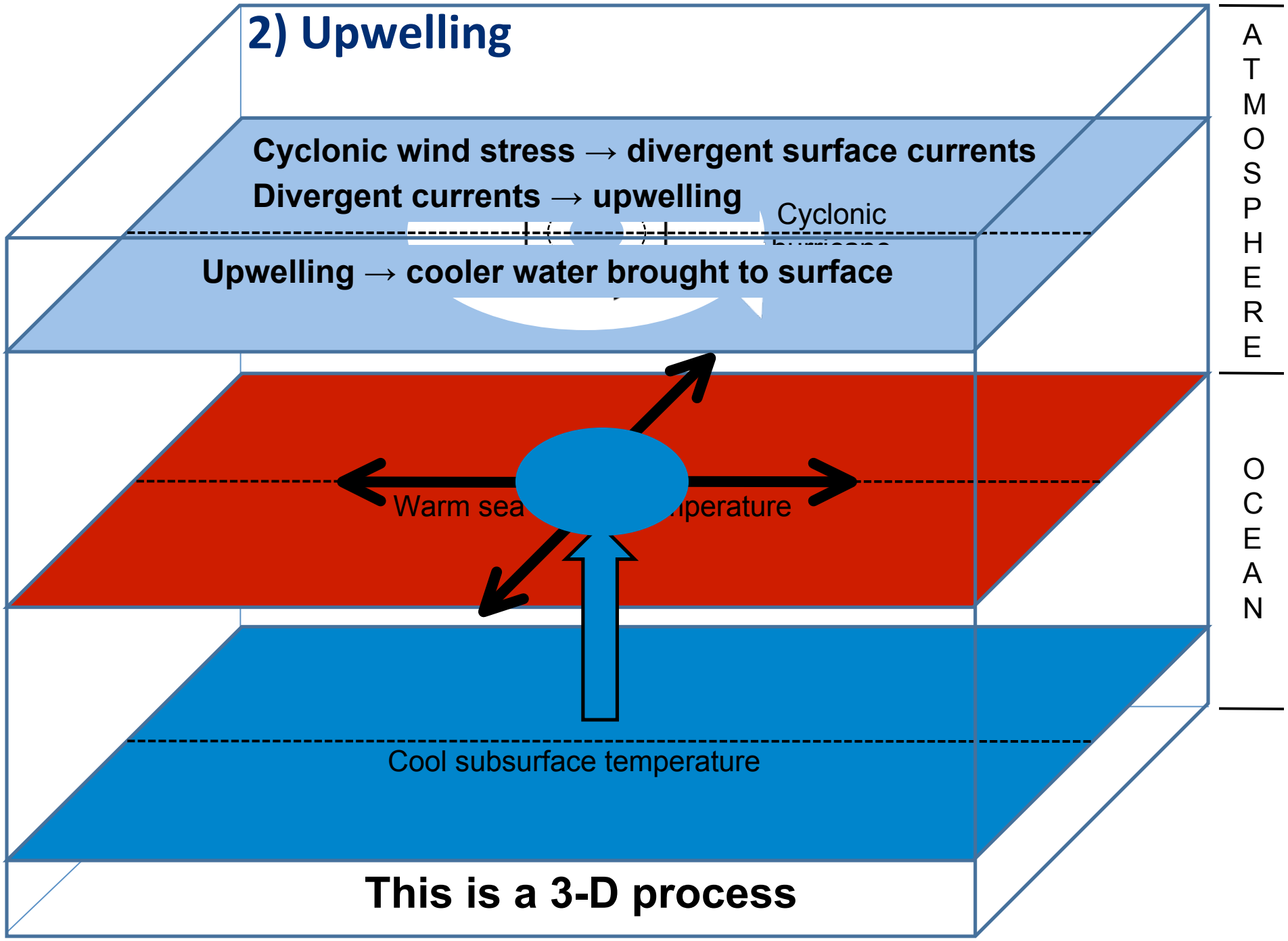
Outline

- Limitation of one-dimensional ocean models for coupled hurricane-ocean model forecasts (1-D vs. 3-D)
- Improving the ocean initialization of coupled hurricane- ocean models using feature-based data assimilation
- Impact of a warm ocean eddy's circulation on hurricane-induced sea surface cooling with implications for hurricane intensity
- Improving the air-sea momentum flux parameterization and developing a new coupled hurricane-ocean-wave model framework
- Future plans under JHT funding

Storm-core SST reduction

- Evaporation from sea surface provides heat energy to drive the hurricane
- Energy decreases if storm-core SST decreases
- SST can decrease in the hurricane's core by:
  1) **Vertical mixing/entrainment**
  2) **Upwelling**
  3) ~~**Horizontal advection of a surface cold pool**~~ **Later…**
  4) ~~**Heat flux to the atmosphere**~~ **Small by comparison**


1) Vertical mixing/entrainment
Wind stress → surface layer currents
Current shear → turbulence
Turbulent mixing → entrainment of cooler water
Sea surface temperature decreases
Subsurface temperature increases
This is a 1-D (vertical) process
ATMOSPHERE
OCEAN

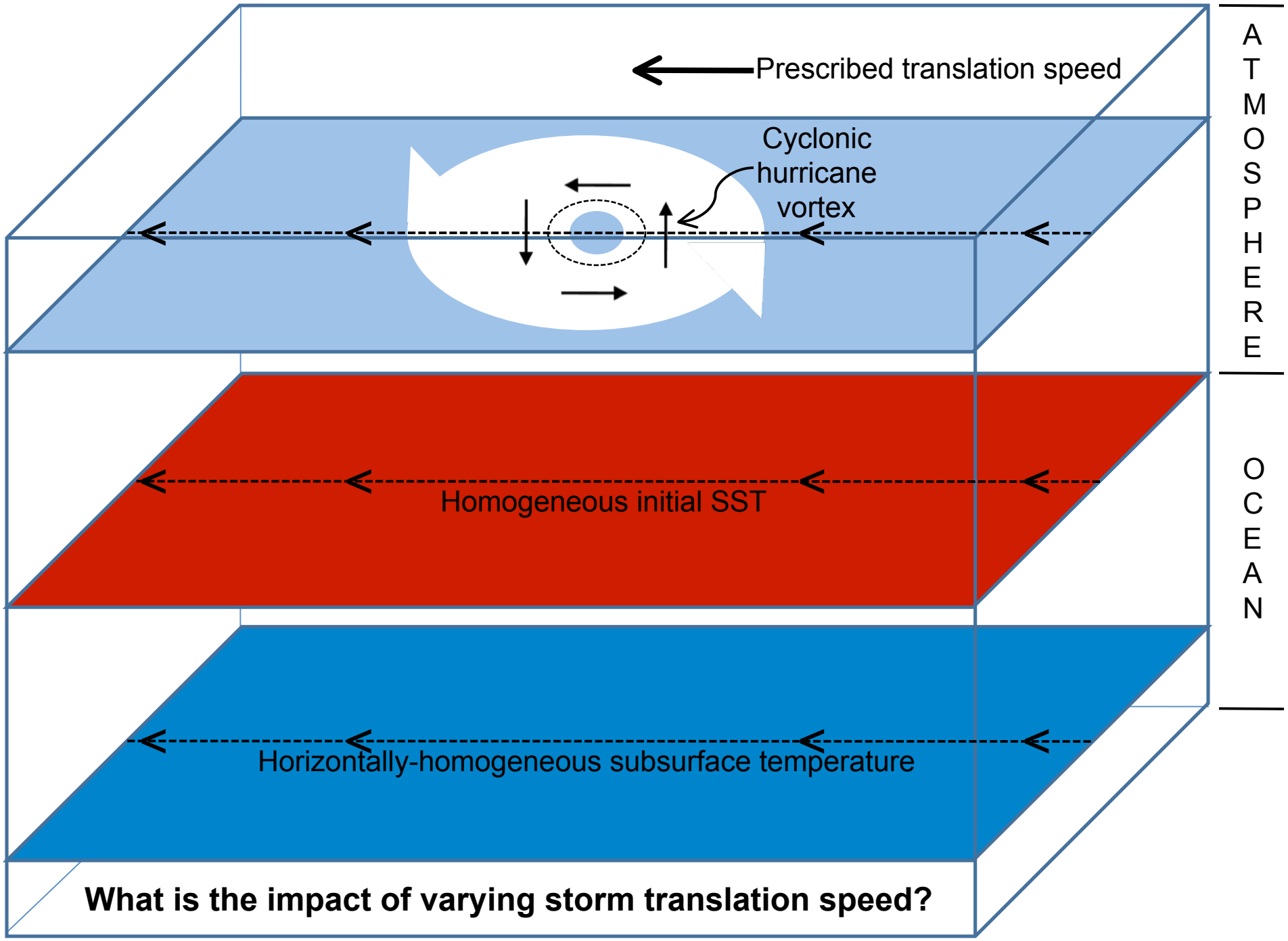

2) Upwelling
Cyclonic wind stress → divergent surface currents
Divergent currents → upwelling
Cyclonic
Upwelling → cooler water brought to surface
ATMOSPHERE
Warm sea
perature
OCEAN
Cool subsurface temperature
This is a 3-D process

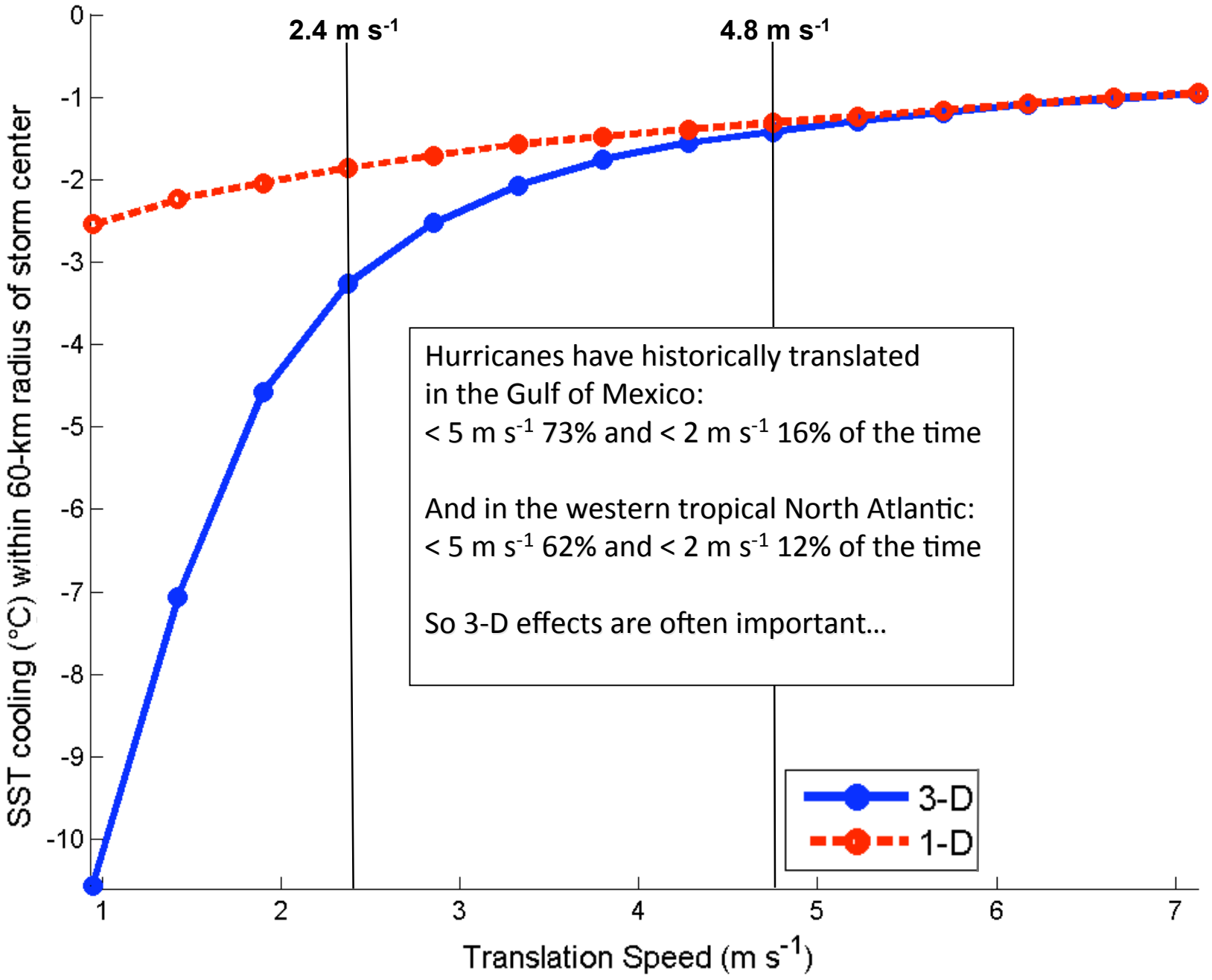
Motivation

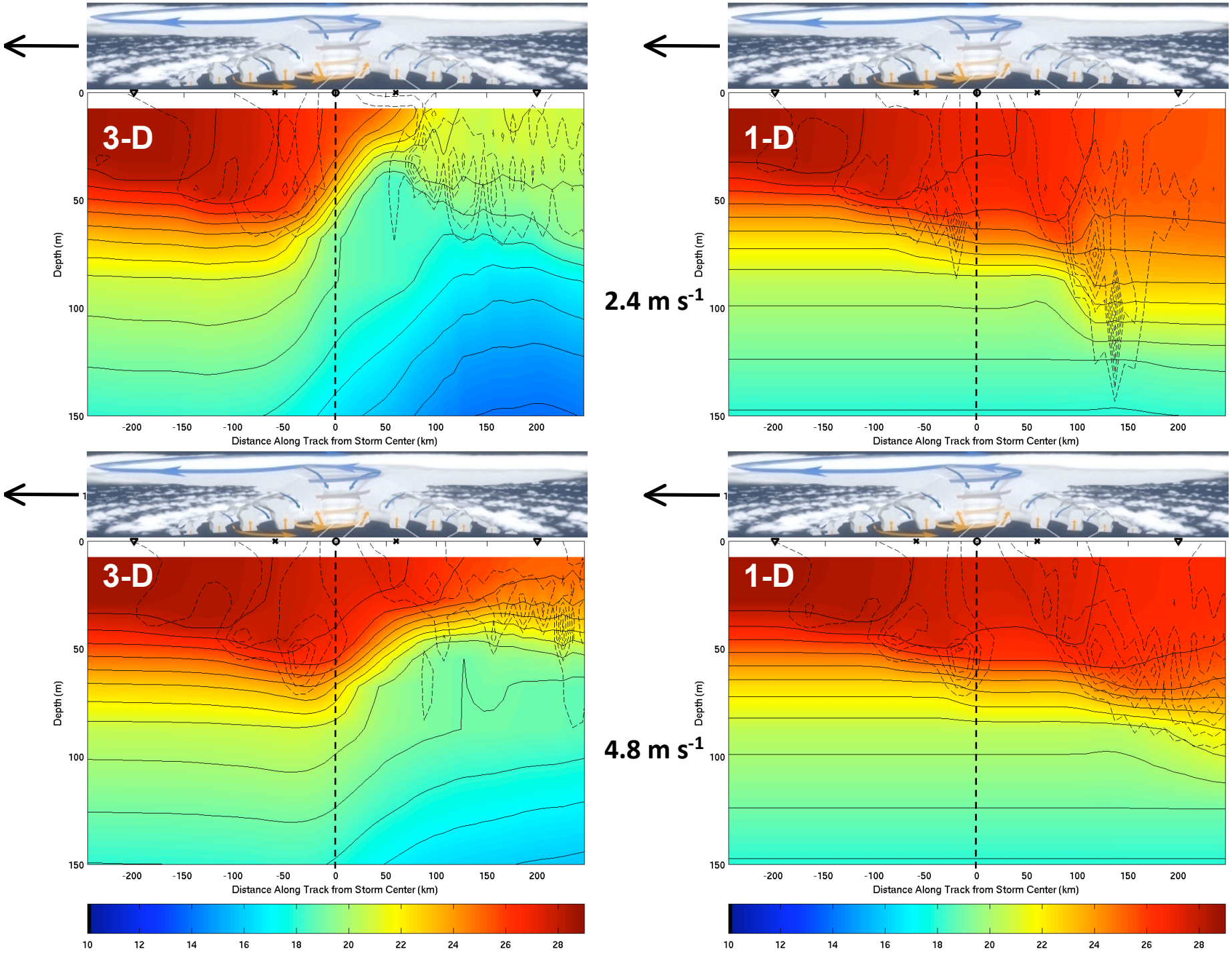
- **Vertical mixing/entrainment** is assumed to be the dominant mechanism for storm-core SST reduction

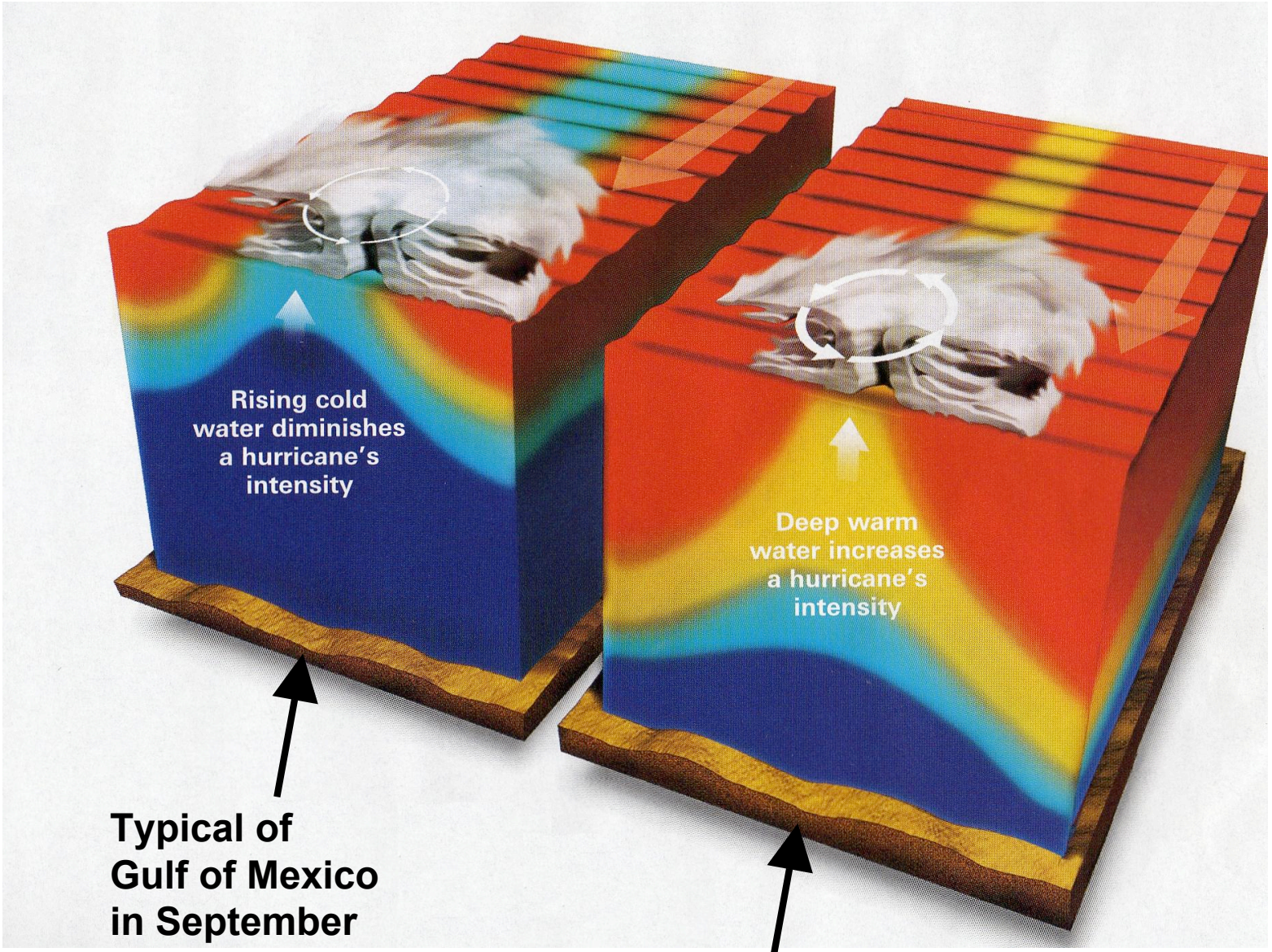
- **Upwelling** is neglected in coupled hurricane-ocean models that use a 1-D (vertical) ocean component

- **Is vertical mixing/entrainment >> upwelling?**

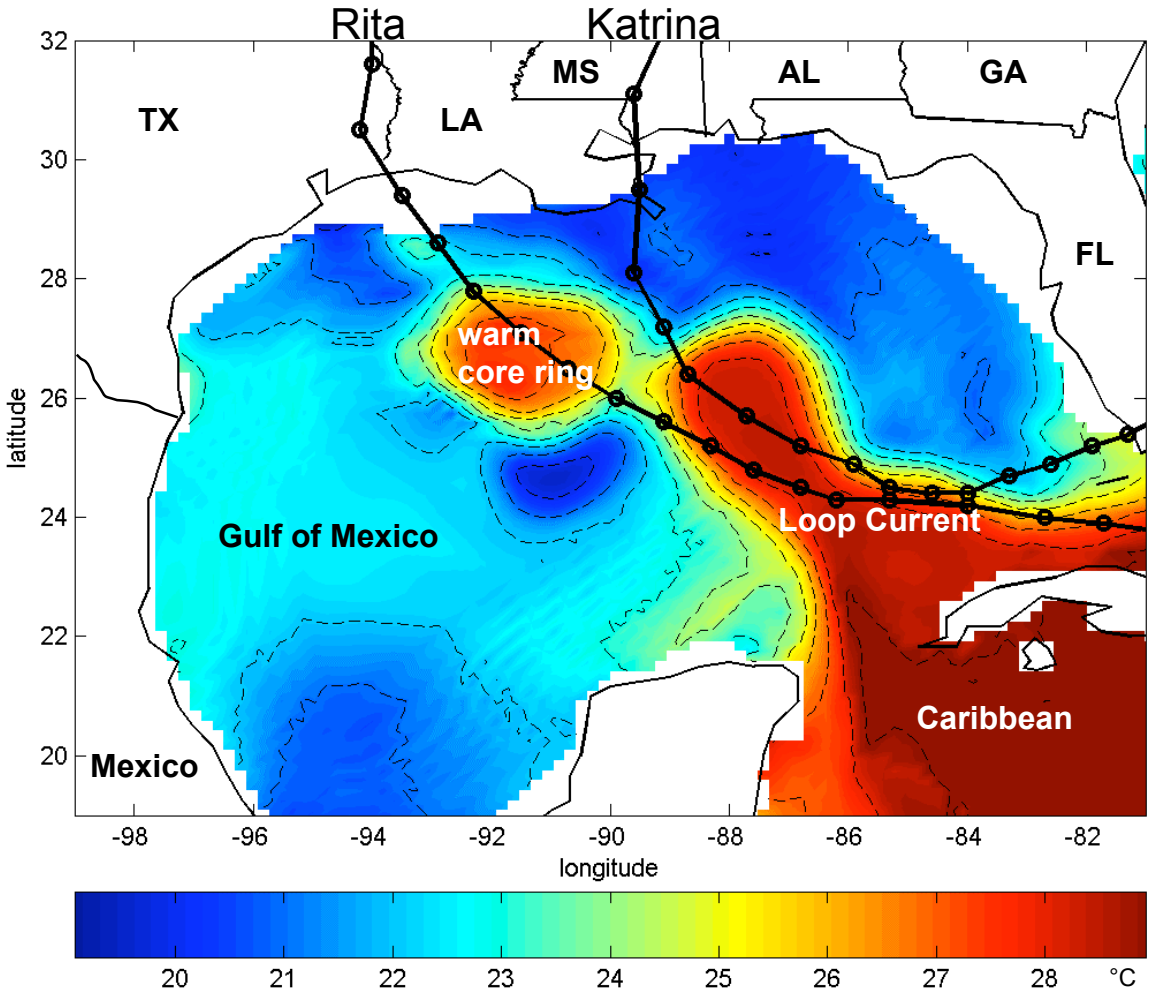

Prescribed translation speed
Cyclonic hurricane vortex
ATMOSPHERE
Homogeneous initial SST
OCEAN
Horizontally-homogeneous subsurface temperature
What is the impact of varying storm translation speed?


2.4 m s-1
4.8 m s-1
SST cooling (°C) within 60-km radius of storm center
Translation Speed (m s-1)
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
1
2
3
4
5
6
7
Hurricanes have historically translated in the Gulf of Mexico:
< 5 m s-1 73% and < 2 m s-1 16% of the time
And in the western tropical North Atlantic:
< 5 m s-1 62% and < 2 m s-1 12% of the time
So 3-D effects are often important…
3-D
1-D


3-D
1-D
2.4 m s-1
4.8 m s-1
Depth (m)
Distance Along Track from Storm Center (km)
0
50
100
150
-200
-150
-100
-50
0
50
100
150
200
10
12
14
16
18
20
22
24
26
28


Rising cold water diminishes a hurricane's intensity
Deep warm water increases a hurricane's intensity
Typical of Gulf of Mexico in September
Typical of Caribbean in September

Approximate Locations of Oceanic Features During Hurricanes Katrina and Rita (2005)



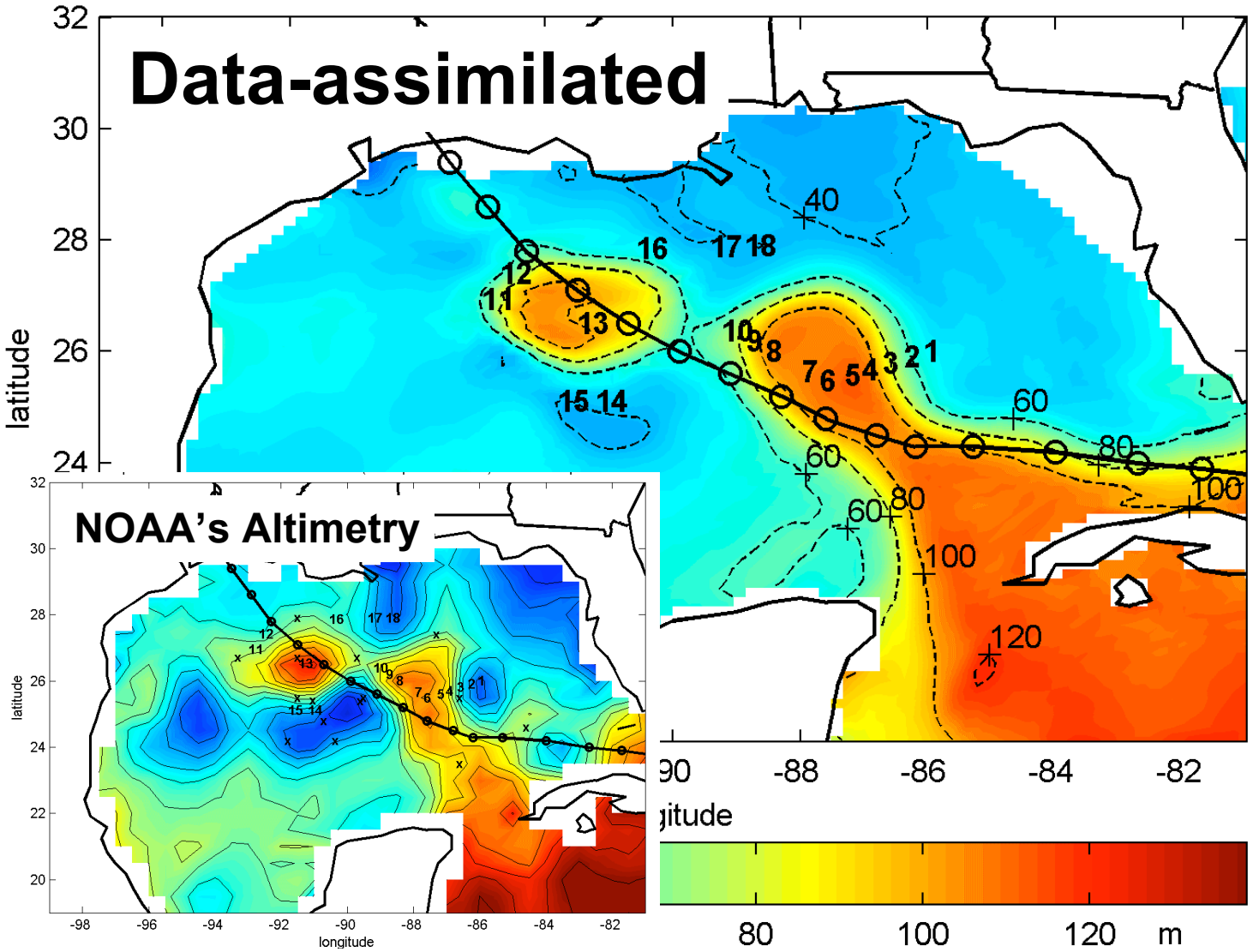
Subsurface (75-m) ocean temperature during Katrina & Rita

Warm Loop Current water and a warm core ring extend far into the Gulf of Mexico from the Caribbean…

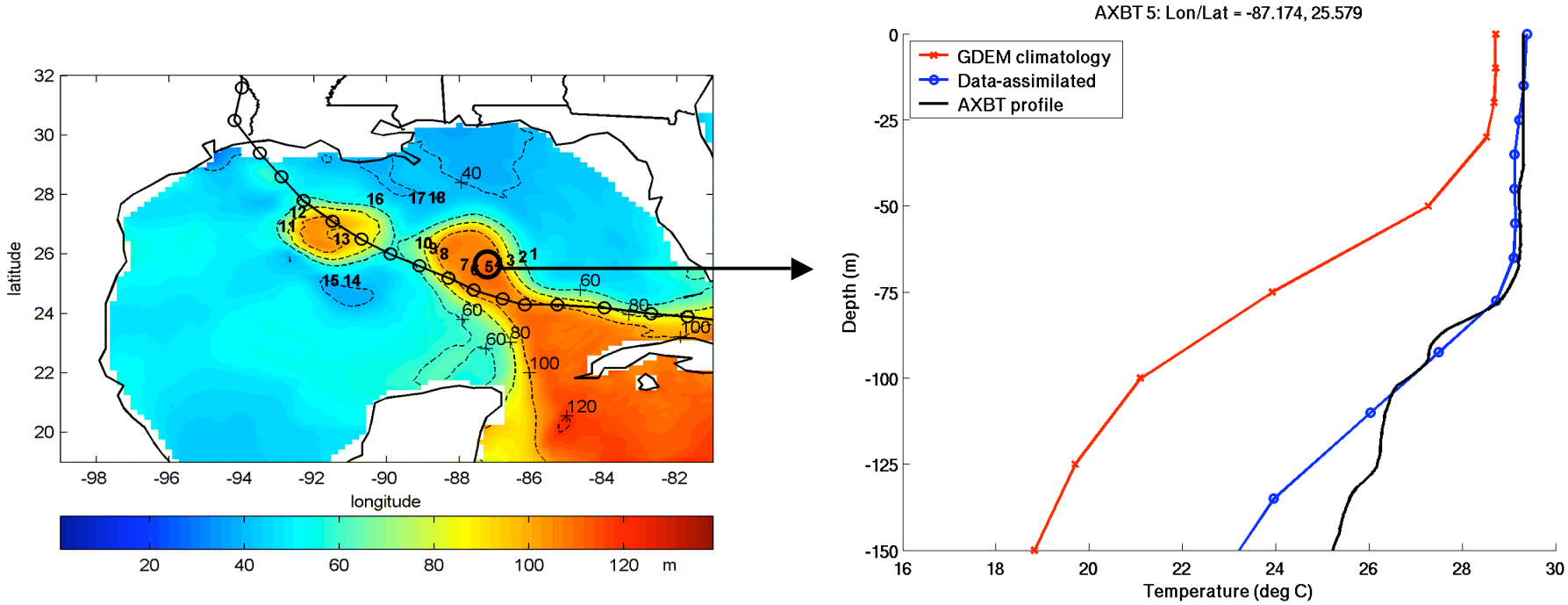
Directly under Rita's & Katrina's track…

But… how do we know the locations of (& how do we assimilate) these features in real-time?

Feature-based modeling procedure implemented in 2006

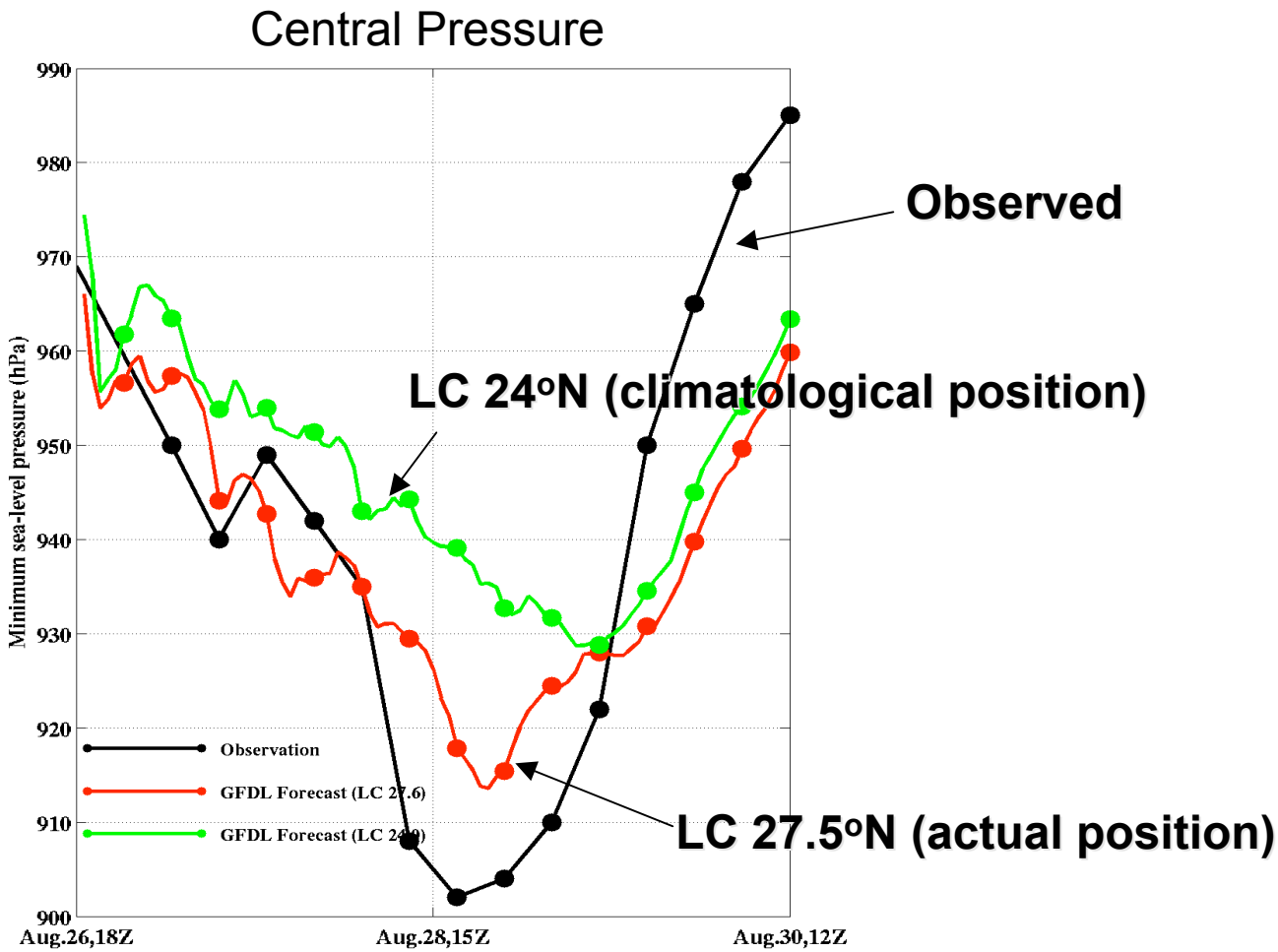


Validating the feature-based model with NOAA/AOML/HRD's AXBTs



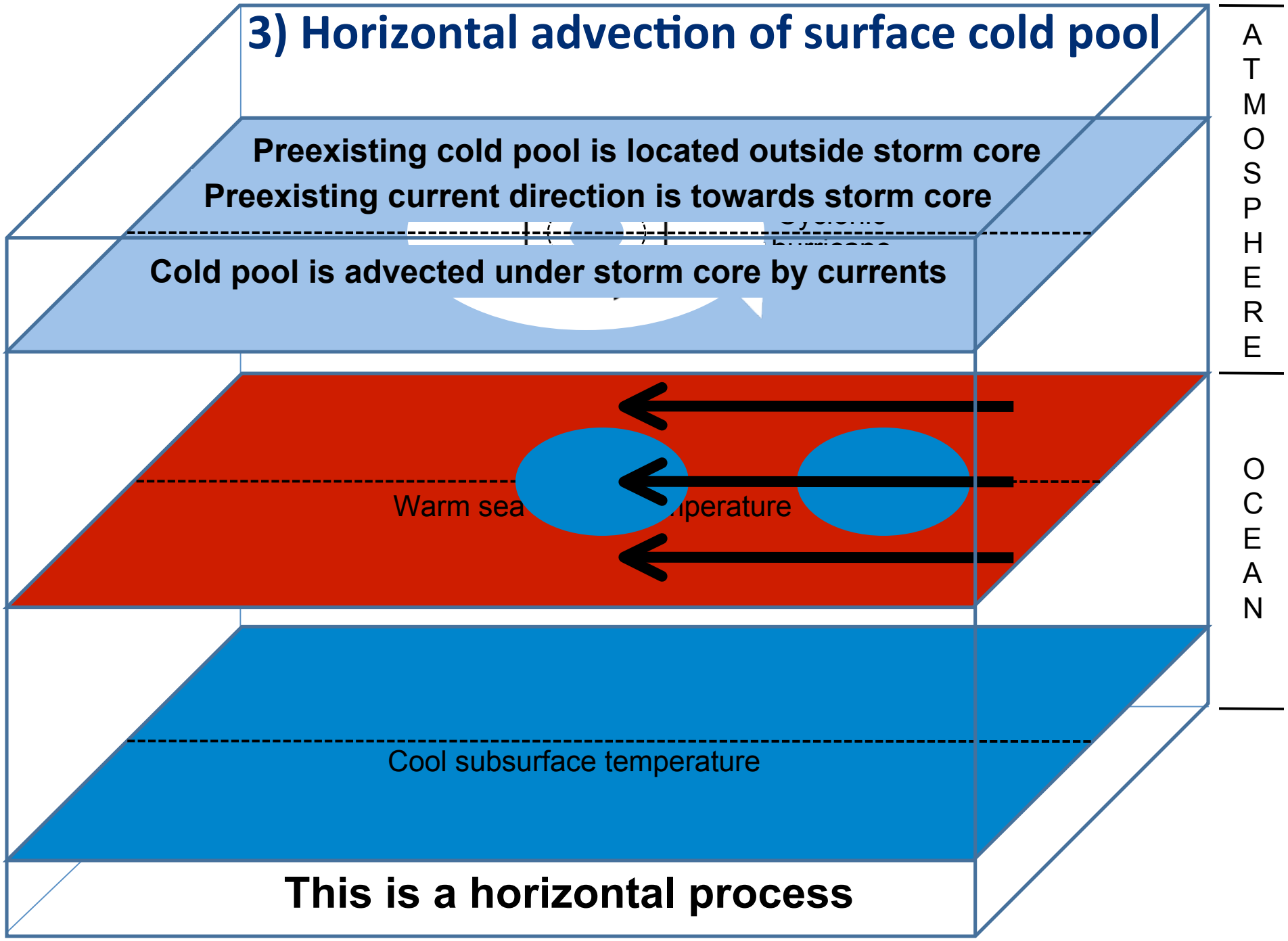
Impact of improved initialization of the Loop Current (LC) on a GFDL model intensity forecast

Hurricane Katrina
Forecast:
Initial time:
Aug. 26, 18Z

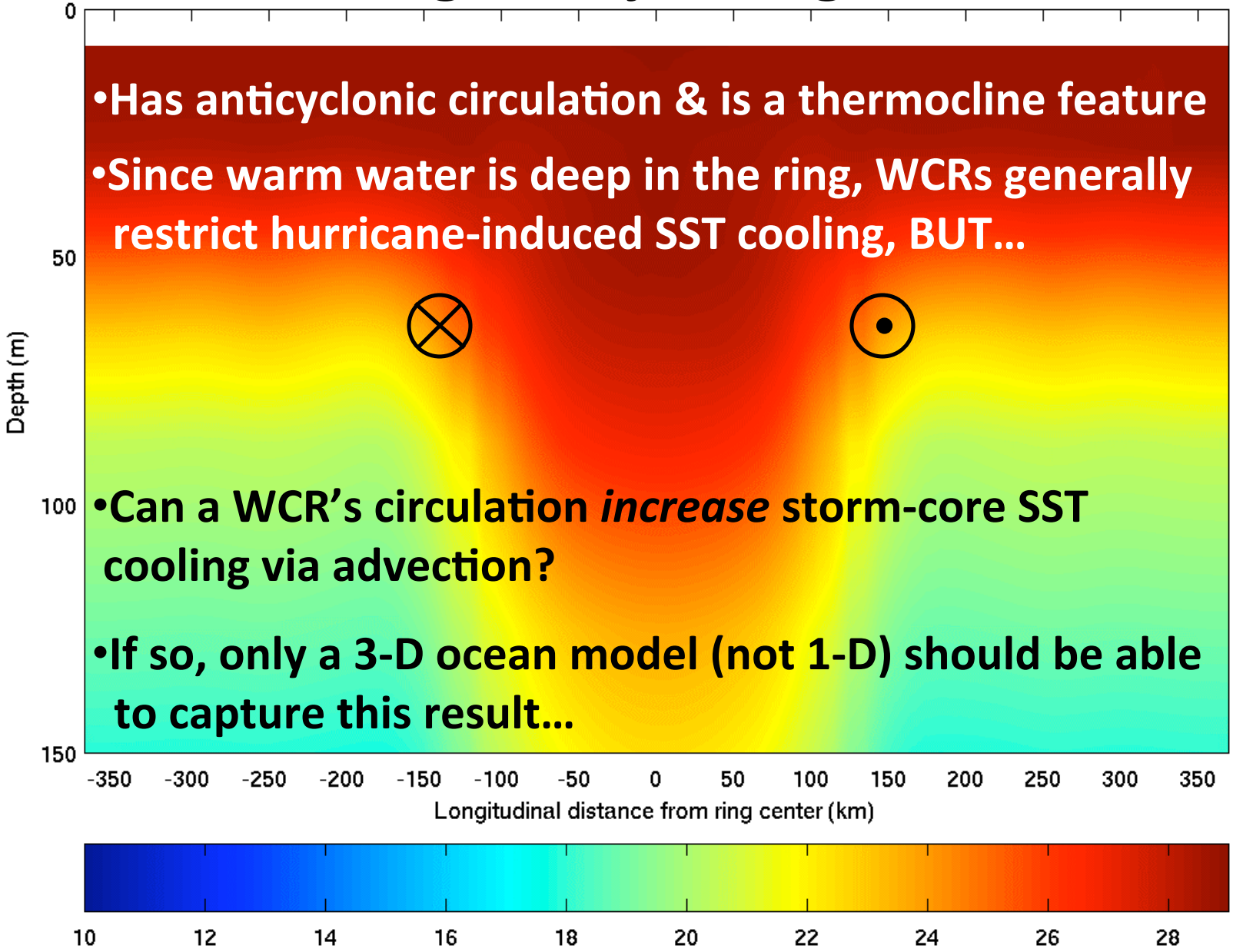


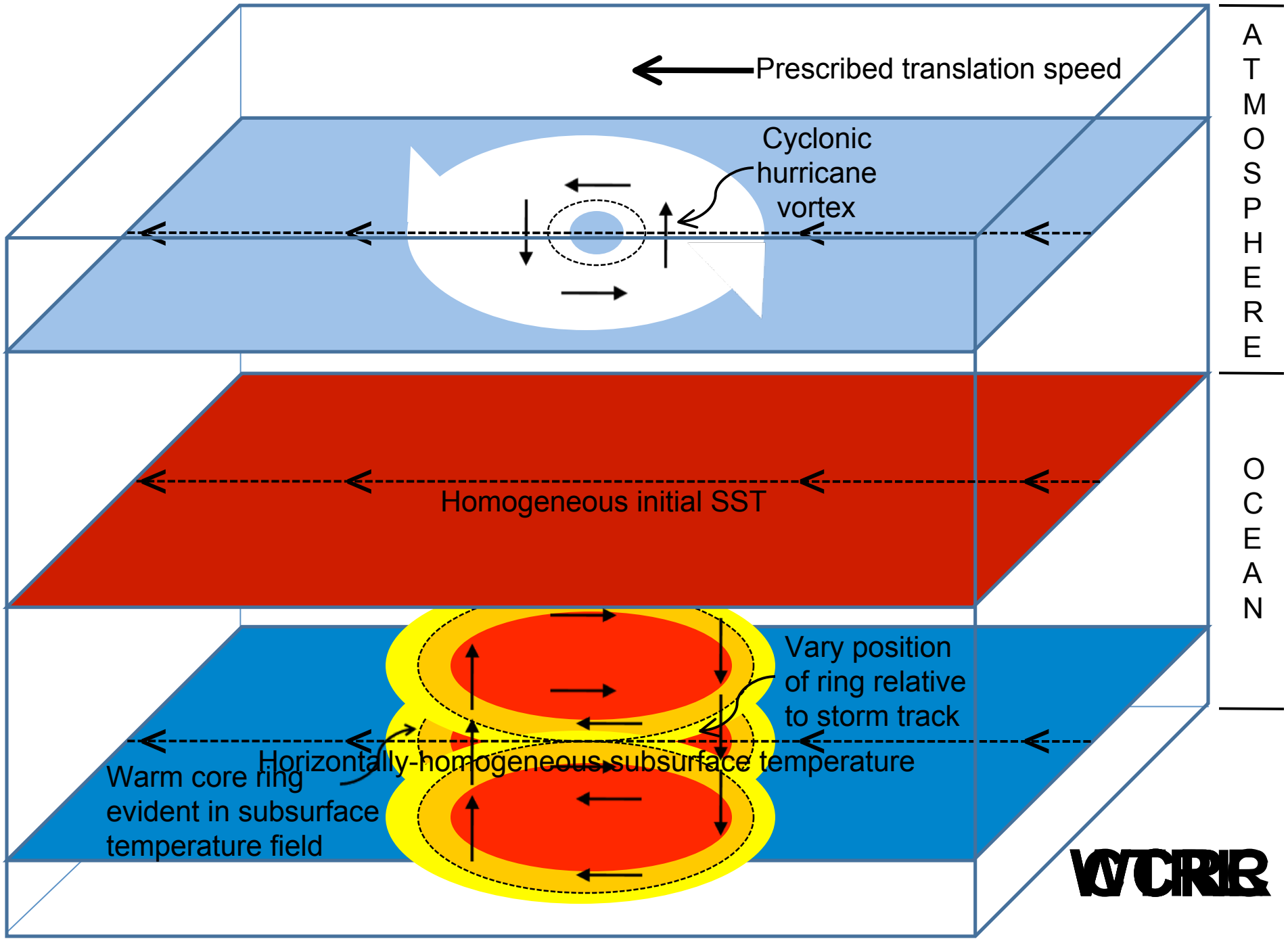
Storm-core SST reduction (revisited)

- SST can decrease in the hurricane's core by:
  1) ~~Vertical mixing/entrainment~~ Discussed earlier
  2) ~~Upwelling~~ Discussed earlier
  3) **Horizontal advection of a surface cold pool**
  4) ~~Heat flux to the atmosphere~~ Small by comparison

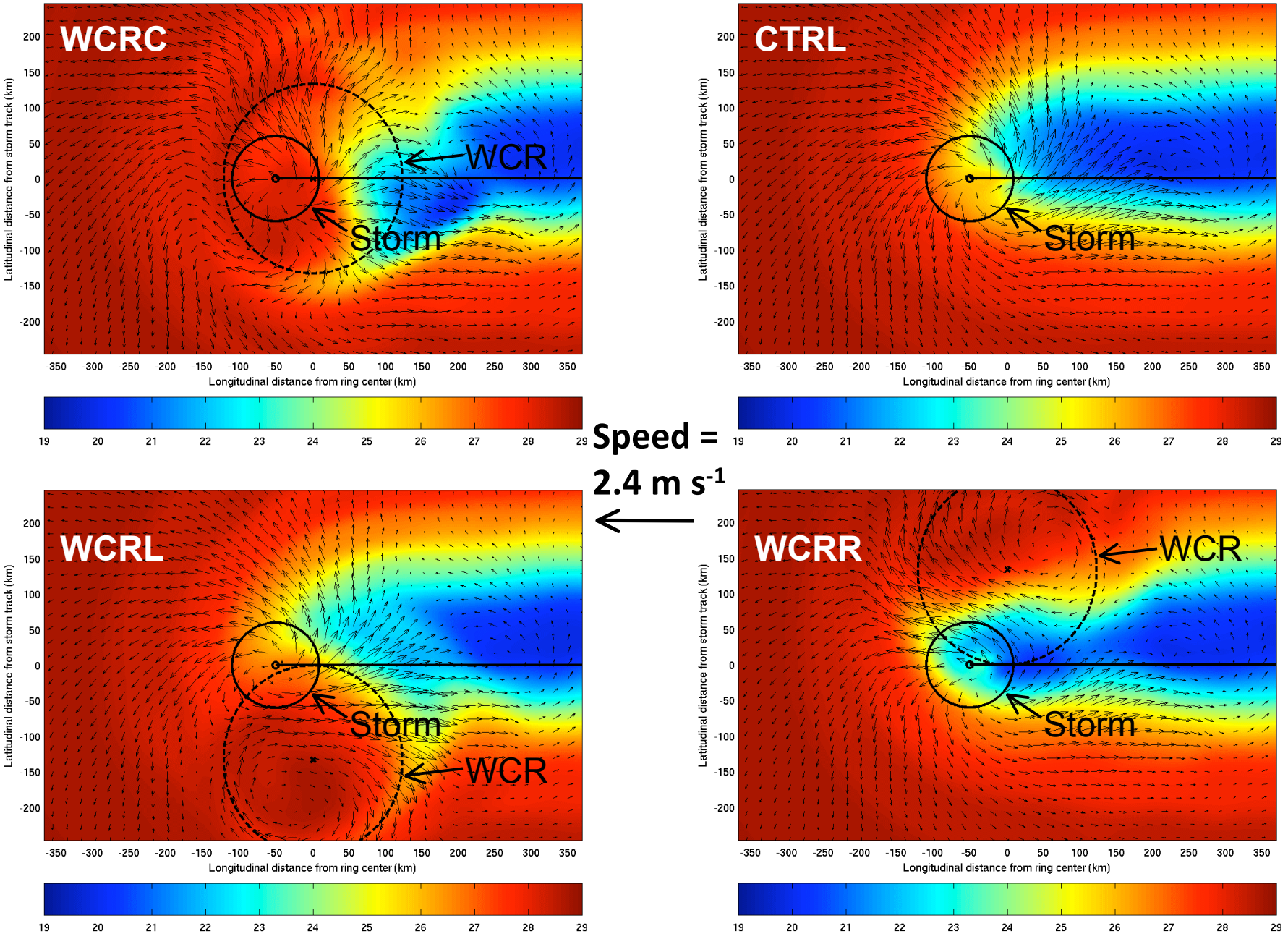

3) Horizontal advection of surface cold pool
Preexisting cold pool is located outside storm core
Preexisting current direction is towards storm core
Cold pool is advected under storm core by currents
Warm sea
perature
Cool subsurface temperature
This is a horizontal process
ATMOSPHERE
OCEAN

Warm Core Ring: Not just high heat content

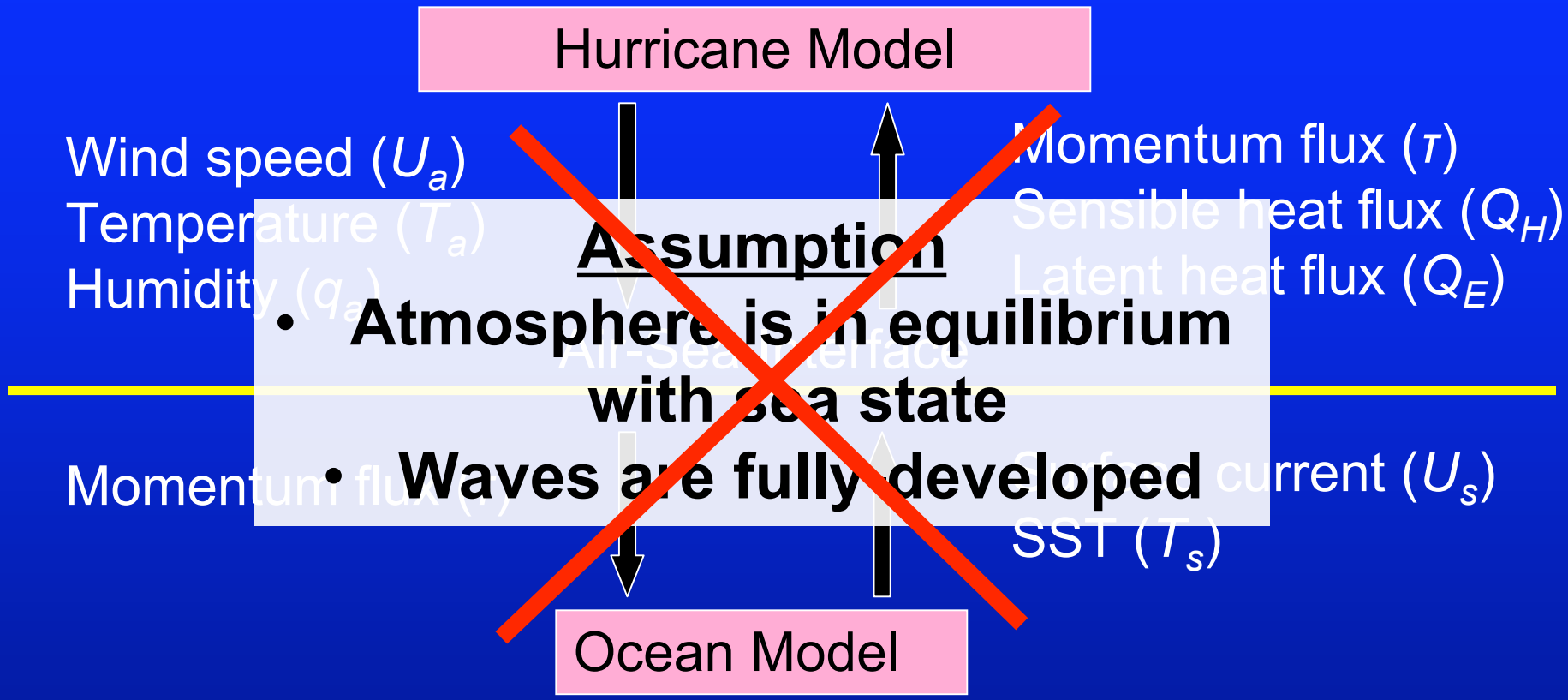



Prescribed translation speed
Cyclonic hurricane vortex
ATMOSPHERE
Homogeneous initial SST
OCEAN
Vary position of ring relative to storm track
Horizontally-homogeneous subsurface temperature
Warm core ring evident in subsurface temperature field

SST & current vectors… storm is ~50 km past center of WCR… 3-D experiments



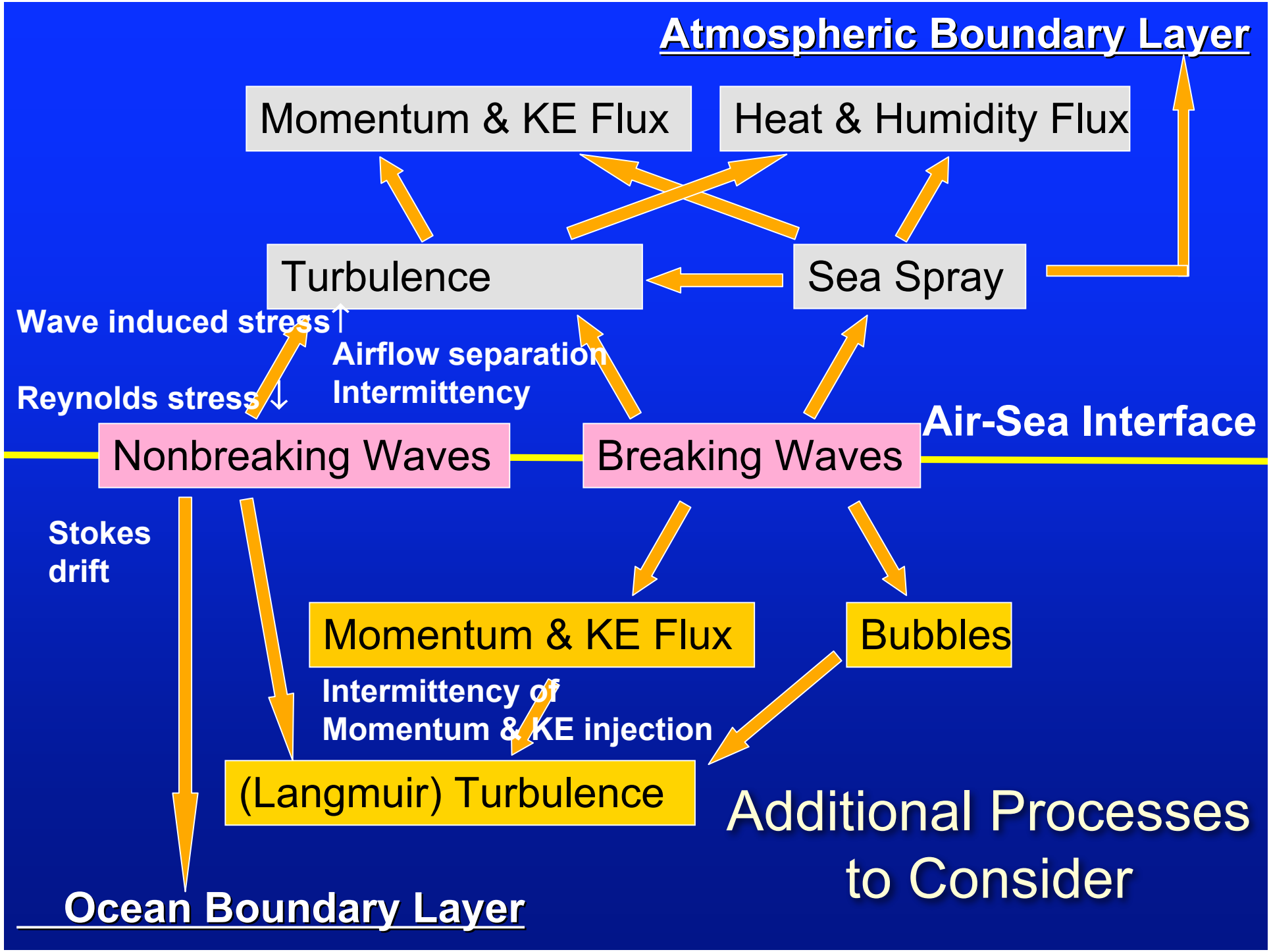
Conventional Coupling Between Hurricane and Ocean Models



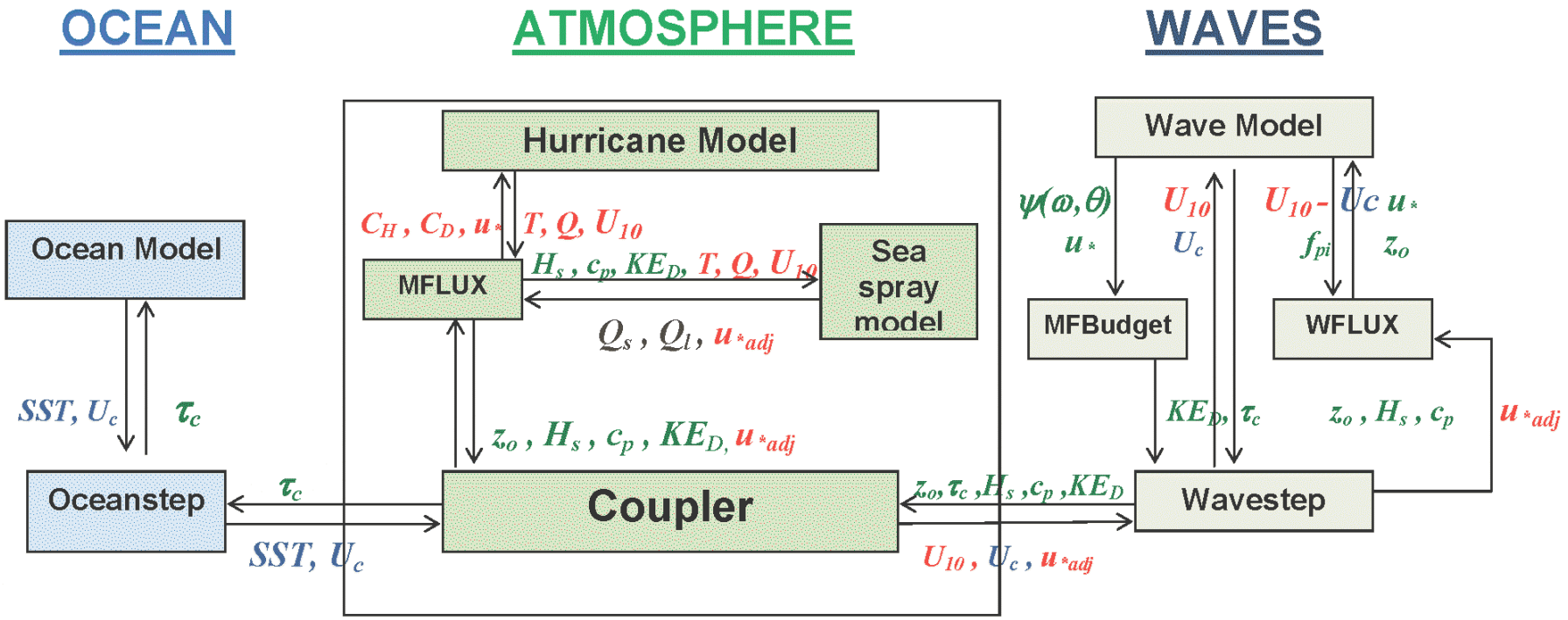
$$\tau = \rho_a C_D (U_a - U_s)(U_a - U_s)$$

$$Q_H = C_H (U_a - U_s)(T_a - T_s)$$

$$Q_E = \frac{L_V}{C_P} C_E (U_a - U_s)(q_a - q_s)$$

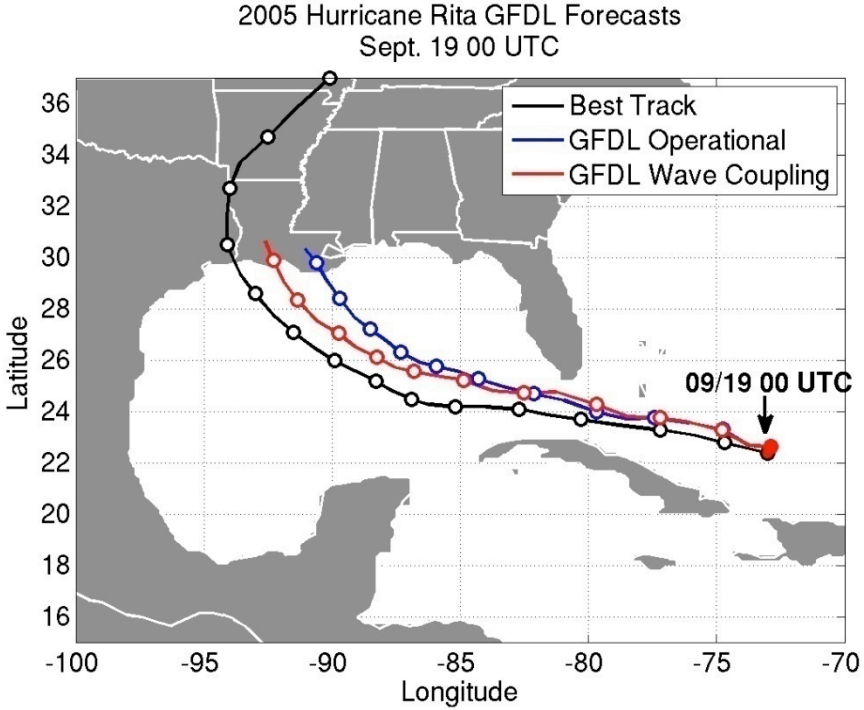

Atmospheric Boundary Layer
Momentum & KE Flux
Heat & Humidity Flux
Turbulence
Sea Spray
Wave induced stress↑
Reynolds stress↓
Airflow separation
Intermittency
Air-Sea Interface
Nonbreaking Waves
Breaking Waves
Stokes drift
Momentum & KE Flux
Bubbles
Intermittency of Momentum & KE injection
(Langmuir) Turbulence
Additional Processes to Consider
Ocean Boundary Layer

Coupled Hurricane-Wave-Ocean Framework

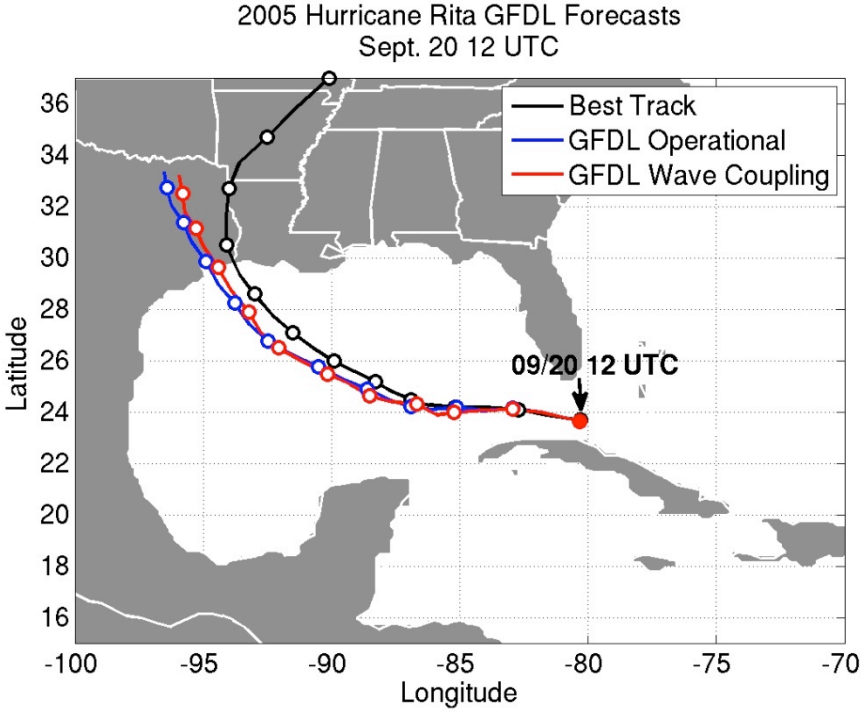


Improved GFDL track forecasts of Hurricane Rita with inclusion of wave coupling

Sept. 19 00Z



Sept. 20 12Z



Future plans under JHT funding

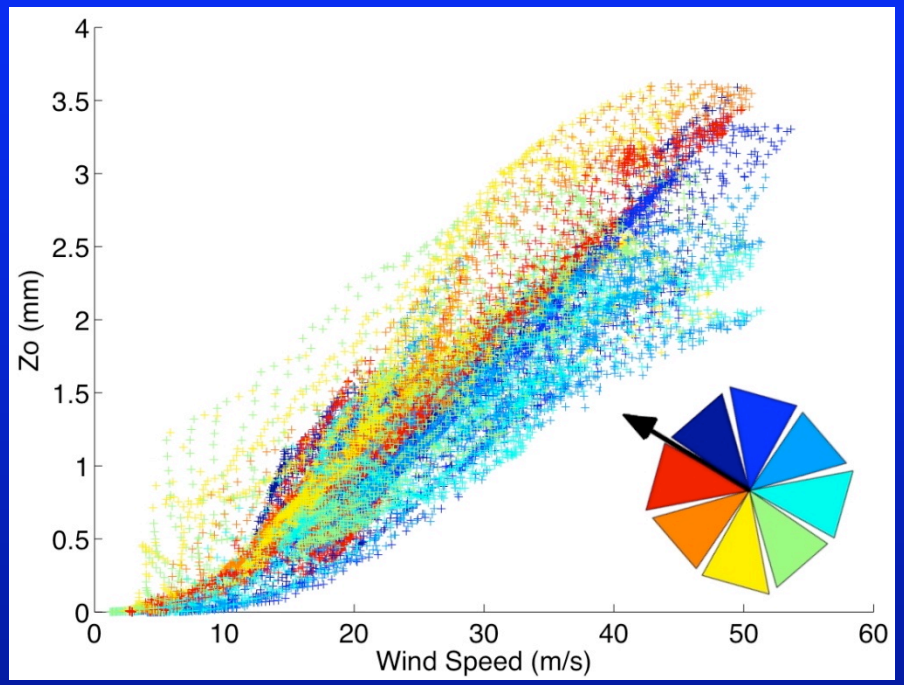
- In both HWRF and GFDN, improve physics of air-sea fluxes, including sea spray effect in collaboration with C. Fairall & J.-W. Bao (ESRL) and HWRF team at EMC
- In both HWRF & GFDN, implement coupled hurricane-wave-ocean model framework (already in GFDL)
- Assist in potential transition of HWRF/POM to HWRF/HYCOM in collaboration with EMC
- Increase GFDN atmospheric model resolution
- Implement Navy's NCODA ocean analysis into the GFDN ocean initialization in the Atlantic basin
- Support HWRF/POM coupled system at the DTC


Hurricane Katrina
28 August 2005
1445 GMT
GOES-12 visible
Questions???

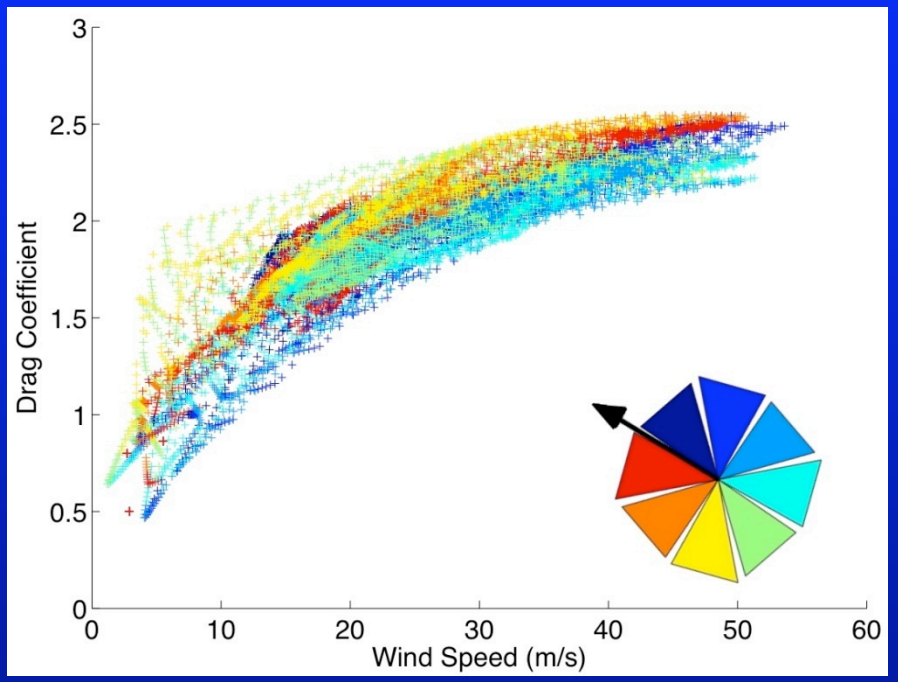
Supplemental Slides….

Sea State Dependence of Surface Parameters

Surface Roughness



Drag Coefficient



Based on the coupled GFDL hurricane-wave-ocean coupled model simulations

Little improvement in GFDL intensity forecasts of Rita with inclusion of wave coupling